INPUT POWER FACTOR CORRECTION IN A SINGLE PHASE AC-DC CIRCUIT USING PARALLEL BOOST CONVERTER

A Thesis submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology in Electrical Engineering

By

RAMAVATH MAHESH
110EE0205

Under supervision of
Prof. Anup Kumar Panda

Department of Electrical Engineering

National Institute of Technology, Rourkela

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DEPARTMENT OF ELECTRICAL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA
ODISHA, INDIA-769008

CERTIFICATE

This is to certify that the thesis entitled **"Input Power Factor correction in a Single Phase AC-DC Circuit Using Parallel Boost Converter"**, submitted by **Ramavath Mahesh (Roll. No. 110EE0205)** in partial fulfilment of the requirements for the award of **Bachelor of Technology** in **Electrical Engineering** during session 2013-14 at **National Institute of Technology, Rourkela.** A bonafide record of research work carried out by him under my guidance.

The candidate have fulfilled all the requirements required for the award of degree.

The thesis which is done by him is based on his own work and he have not submitted elsewhere for the award of degree.

Place: Rourkela

Dept. of Electrical Engineering
National Institute of Technology
Rourkela-769008

Prof. A.K. Panda
Prof. & HOD

ABSTRACT

AC-DC converter is a part of any power supply used in the any electronic equipment's. Power electronic equipment's are being used in injecting low order harmonics, power conversion. Due to these harmonics, the total harmonic distortion is high and input power factor of this system is poor. PFC schemes are implemented in order to get unity power factor and low input current harmonics and distortion in the line currents. With the low power factor, increase in the neutral currents in 3-phase system, transformers and induction motors heat increases in them and hence, there is a need to continuous improvement of the PF and reduction of the input current harmonics is necessary.

The main aim of this thesis is to develop a circuit for the PFC using an active filter by using two boost-converters connected in parallel combination. This will be based on optimized power sharing scheme between them to improve the input current drawn by the load and reducing switching losses. In this project first we done the simulations by using basic circuits without using PFC methods and analysis of the current, voltage waveforms after this, included new components and observed their after effects on input current and input voltage waveforms were observed. The main aim of this project is to improving the input current waveform.

AKNOWLEDGEMENT

On the submission of my thesis report, I would like to extend my gratitude & my sincere thanks to my supervisor **Prof. A K Panda**, Professor and HOD, Department of Electrical Engineering for their constant motivation and support during the course of my work in the last two years. I truly appreciate and value their esteemed guidance and encouragement from the beginning to the end of this thesis. I am indebted to them for having helped me shape the problem and providing insights towards the solution. An assemblage of this nature could never have been attempted with our reference to and inspiration from the works of others whose details are mentioned in references section. I acknowledge our indebtedness to all of them. Further, I would like to express my feeling towards my parents and God who directly or indirectly encouraged and motivated me during this dissertation.

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INTRODUCTION:

An ideal single phase supply for domestic appliances is given by 230 V, 50 Hz. However the power system has an impedance in the circuit which always limits the flow of line current in the circuit of the power system. This impedance is not completely avoided or nullify its effect to a much lower level. This results in the voltage difference between substation power supply and the consumer side. Voltage is less in the consumer side. These devices have mains rectification circuits which is the main cause of main harmonic distortion. There were lot of such devices & they will be drawing reactive power from the same supply system resulting in significant amount of reactive current flow and generating harmonics. Both of the above affect the PF of the transmission line. The former affects the displacement PF while the latter one affects the distortion PF of the system. PF mainly focus on the quantity of usable and wastage of the power in the power system. The better the PF the better is the degree of power utilization and lesser the waste. Hence it is required to improve the PF by some means or other methods [1].

In most of the electronic devices which requiring AC-DC converters need the DC output voltage to be regulated with good performance. Typically most of the circuit used earlier are not of this kind so they are affecting the utility system and affecting the loads connected to the systems and causing other adverse effects on the power systems. For marinating the power quality of the power system [1]. From the earlier days electronics engineers are concentrating on the developing new concepts and approaches for the best utility to meet these standards. The circuits developed for this purpose are called the power factor correction circuits. Increase in consumer electronics, the power quality is decreasing and the reactive power drawn from the supply system is increasing. This is because of use of rectification of AC input and the use of a bulk capacitor after the diode bridge rectifier [1]. Number of methods are developed for the power factor correction and harmonic reduction were developed but few of them were accepted for the good performance of the utility system [1].

1.1 NON-LINEAR LOAD & EFFECT ON DISTRIBUTION SYTEM:

The instrument connected to a power system requires some kind of rectification, as this system produces non sinusoidal line currents due to the nonlinear characteristics of the load connected to the system. Diode rectifiers which are connected to the input side of the power system can convert the AC input to DC output. Single phase diode rectifiers are used for the low power applications and for the high power applications 3-phase rectifier circuits are used. In both of these single phase and 3-phase bridge rectifiers a large capacitor is used in the output side of the rectifier for obtaining the DC output voltage with a lower ripple [2]. Because of this the line current is non-sinusoidal. In all case mostly odd harmonics amplitude are considered with respect to the fundamental component. While the effect on the system with the single phase low power nonlinear load characteristics can be considered as negligible, but the total effect on the system is considered if more number of such loads are connected to the system. Line current harmonics have very adverse effects on the distribution and consumer network systems [2].

These effects include [3]:

- There will be more losses and overheating of core of the transformer.
- Excess current can flow in neutral conductor of three phase four wire system with neutral.
- Power factor will reduce.
- Electrical resonances in the power system
- Premature aging and failure of capacitors and insulation.
- The distorted line voltage may affect other consumers connected to the network.
- Telephonic interference will takes place.
- Errors can occur in metering instrument.
- Increase in the audio noise.
- Distortion of line voltage via impedance of the line.

1.2 STANDARDS REGULATING LINE CURRENT HARMONICS:

1.2.1 IEC 1000-3-2 STANDARD:

1. This standard is applicable to instrument with a rated current up to the RMS current of 16A, connected to 50Hzor 60 Hz, and RMS voltage of range from 220-240V single-phase or for the three phase supply of 380-415V [2].

2. All the electrical instruments are connected to the system are classified into 4 classes as A, B, C and D, for all of these classes specific limits are set for the harmonic content should present in them [2].
3. These limits do not apply for the instrument with rated power less than 75W, other than lighting instrument [2].

Class A: Instrument which is not specified in anyone of the all the three classes comes under this type of class [2].

Class B: Portable tools, and nonprofessional welding which is of arc type comes under this type of class [2].

Class C: Lighting equipment's comes under this type of class except for dimmers and incandescent lamps and these are belongs to the class A type [2].

Class D: Instruments which are having input power less than 600W like personal computers and television receivers comes under this type of class [2].

1.2.2 STANDARD IEEE 519-1992:

Gives recommended practice & requirements for harmonic control in the power systems for both individual customers connected to the network and utilities. The limitation for the input line currents and current harmonics are given as a percentage of the maximum demand of the load current I_L at the point of common coupling (PCC) at the utility side. They decreases as the ratio of I_{SC}/I_L decreases, i.e., the limits are lower in weaker grids [1].

Limits in standard IEEE 519-1992:

Table 1.1: Odd harmonic limits [1]:

I_{SC}/I_L (%)	$h<11$	$11\leq h<17$	$17\leq h<23$	$23\leq h<35$	$35\leq h$	TDD*
<20	4	2	1.5	.6	.3	5.
20 to 50	7.0	3.5	2.5	1.0	0.5	8
50 to 100	10.0	4.5	4.0	1.5	0.7	12
100 to 1000	12.0	5.5	5.0	2.0	1.0	15
>1000	15.0	7.0	6.0	2.5	1.4	20

*TDD=Total Demand Distortion [1]

We need to reduce the input line current harmonics in order to follow with the standard. If the power factor of an electric load is lower than unity, the apparent power which is delivered to the load which is connected to power system is greater than the real power drawn by the load. The real power is only doing the useful work for the load to run, and but the apparent power which gives the current that is flowing into the load which is connected to the power system, for a given load voltage. PFC is a technique which is used to make the power factor to be increased to a value which is near to the unity by using few elements in the PFC methods [3].

2.1 POWER FACTOR:

Input power factor of electrical power system is defined as [3],

$$\text{PF} = \frac{\text{Active Power}}{\text{Apparent Power}} \tag{I}$$

For purely sinusoidal voltage and current,

$$\text{PF} = \cos\varphi \tag{II}$$

Let us consider for an input voltage of V and a line current of I,

VI $\cos\varphi$, VI $\sin\varphi$ and VI is the active power in kW, reactive power in kVAR and apparent power in KVA.

Power factor is the measure of how much the input line current and input voltages are distorted from the original shape and phase shift between them. Consider an inductor circuit, which draws a current I from the supply mains lagging behind the supply voltage V by an angle [2].

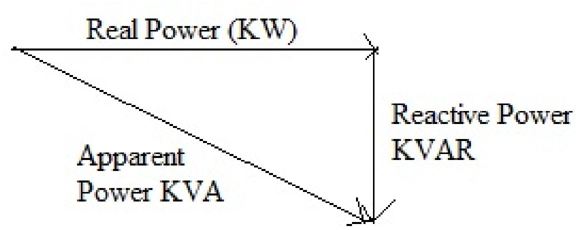


Fig: 2.1. Power triangle [2]

Reactive power, KVAR = kVAsin φ = (kVAcos φ) $\frac{\sin\varphi}{\cos\varphi}$

$$= \tan\varphi$$

When the load is having the nonlinear characteristics then definitely the line current follows the non-sinusoidal nature. For the sinusoidal voltage & non-sinusoidal current, the PF can be expressed as follows [2],

$$PF= \frac{V_{rms} I_{1rms}}{I_{rms} V_{rms}} Cos\emptyset = \frac{I_{1rms}}{I_{rms}} Cos\emptyset = K_p \ Cos\emptyset \quad (III)$$

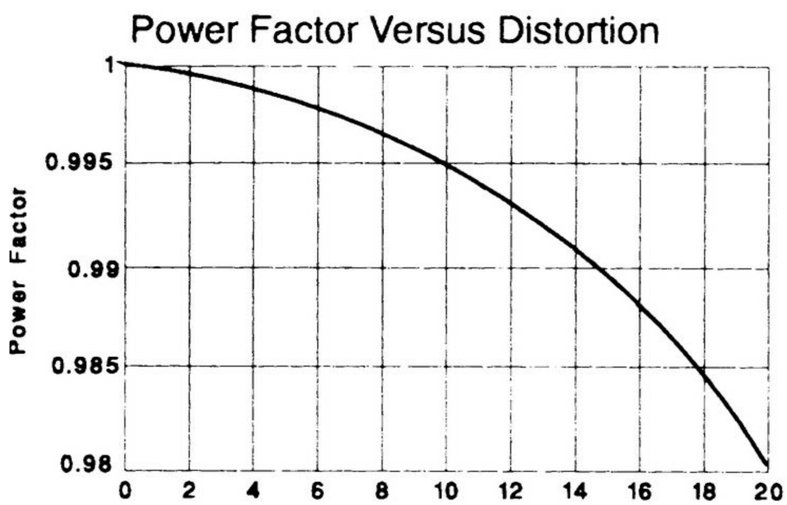
$$K_p = \frac{I_{1rms}}{I_{rms}}, K_p \in [0,1] \quad (IV)$$

K_p , Describes the harmonic content of the current with respect to the fundamental. Therefore, the PF depends on both harmonic content and displacement factor. K_p Is referred to as purity factor or distortion factor [2].

Total harmonic distortion THD_i is given by the following equation [2],

$$THD_i = \frac{\sqrt{\sum_{n=2}^{\infty} I^2 n,rms}}{I_{1rms}} \quad (V)$$

$$K_p = \frac{1}{\sqrt{1+THD^2}} \quad (VI)$$



Fig; 2.2. Power factor versus distortion [2]

IEC 1000-3-2 Standard, which sets limitation in the harmonic content which is present in input current but it will not specially adjust factor K_p or the THD of the input current. Values of the K_p and THD_i, is given according to the standards given with the IEC 1000-3-2 is attained near to unity PF depends upon the quantity of power. For the quantity of low power, if there is a closely small distorted input line current will follow with standards given. Along with above one, it can be observed that the K_p of the waveform with an average THD_i is nearly equals to one, K_p = 0.989 for the THD_i= 15%. Few points can be noted from the above phenomenon [2]:

- Power factor is not completely decreased by the harmonics present in the input line current, unless the amplitude of the harmonics is very high [2].
- It doesn't mean that low harmonics in the input line current will not guarantee the improved high power factor [2].

2.2 Advantages of high power factor:

- ✓ Voltage distortion is reduced.
- ✓ All the power to the load is active.
- ✓ Smaller RMS value of current.
- ✓ More number of loads can be fed from supply system.

2.3 RESEARCH BACKGROUND:

Most of the studies on the power factor correction for the nonlinear loads is mainly associated to reducing of the harmonic content present in the input line current. There are several methods are present in order to get power factor nearly equal to unity or unity in the input side [4]. The distortion in the shape of the input current can be again improved by the use of LPF in the input and output sides. Depending on whether switches which are controlled using an external control input are used or not. In general PFC methods are divided as "Passive PFC" and "Active PFC" [4].

The Committee of European for the Electro technical Standardization – CENELEC, IEC 555-2 standard was substituted by the IEC 1000-3-2 standard which is followed by the CENELEC as European EN 61000-3-2 standard [2]. There are several techniques are there to achieve unity power factor using the PFC, Depending on whether switches which are controlled using an external control input are used or not. They are categorized as active and passive [4].

2.3.1 Passive PFC:

In this type of PFC circuits, only the passive elements are being used along with diode bridge rectifier, in order to improve of the input power factor and shape of the line current in the system. Using this PFC, input power factor of the system can be increased from the value 0.7 to 0.8 nearly. With the increase in the input voltage of the supply system, the size of circuit used for power factor correction with more components will be increased and the cost will also increase. The main objective of the PFC is, filtering input current harmonics in line current. These currents harmonics can be filtered by a using LPF and only allow the fundamental wave and stopping all the odd harmonics to improve the power factor. Using the passive PFC, current harmonics can only be decreased to a certain limits and the power factor cannot reached to a value near to unity. The output voltage cannot be controlled in this PFC circuit [4].

Advantages:

- It is simple in structure.
- It is more reliable and rugged.
- Equipment's used in passive PFC will not generate high frequency EMI [8].
- The cost required to process this method is very low.
- High frequency switching losses are not present in this method and it is insensitive to noise and surges.

Disadvantages:

- The size of filter will increases.
- Dynamic response of the system is very low.
- Output voltage control is difficult and it is not possible.
- As the inductors and capacitors present in the circuit, there will be a chance of interaction between the elements in the circuit or there will be a chance to interact with the system.
- With the use of filters in this method harmonics can be decreased but the fundamental component of the line current will shift its phase from the original phase [5].
- The load connected to the system decides the shape of the input line current.

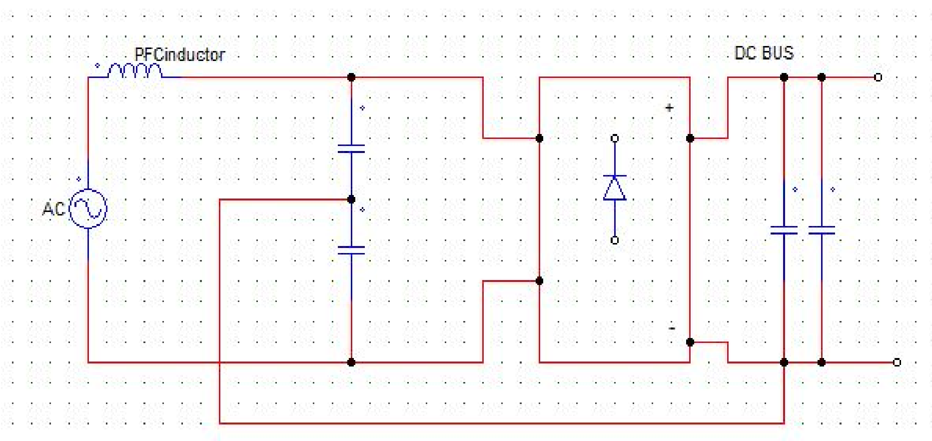


Fig: 2.3. Passive PFC Circuit [3]

2.3.2 Active PFC:

An active power factor correction circuit is designed to control the power drawn by the load in the electrical system and it obtains a power factor near to unity. Any active PFC designed for power factor improvement can works as by controlling the current drawn by the load from the supply system and making it to follow the source voltage waveform. The components used in this method are to correct the shape of the input current waveform and to get the output voltage which is controllable [5].

According to the frequency of switching the active PFC solution can be divided into two classes [5].

1. **The active PFC due to low frequency**: In this class switching of circuit takes at low order harmonics [5].
2. **The active PFC due to high frequency:** In this class of circuit switching frequency is greater than the line-frequency [5].

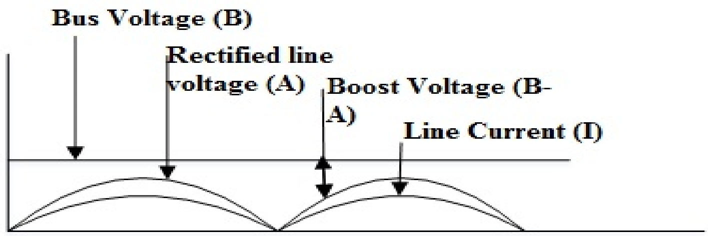
The power factor value obtained in this circuit is more than 0.9. And further the value of power factor can be increased to a higher value to reach unity can be obtained by adding some filtering elements to the circuit [3]. With the active PFC circuit one can determine the input voltage automatically. And the size of the circuit is smaller than the one in case of passive PFC circuit [5]. Harmonics in this case are decreased to the lower values

Advantages:

- System weight low as compared to the passive PFC circuit.
- Size of the system is small and power factor value can be reached to unity approximately.
- Decreases the harmonics to lower values.
- It will automatically corrects the AC input voltage.
- It can be possible for it to operate in full rated voltage.

Disadvantages:

- Design of this system is a bit complex as more number of elements are present.
- Highly expensive due to its need to provide extra elements present in the circuit[1]



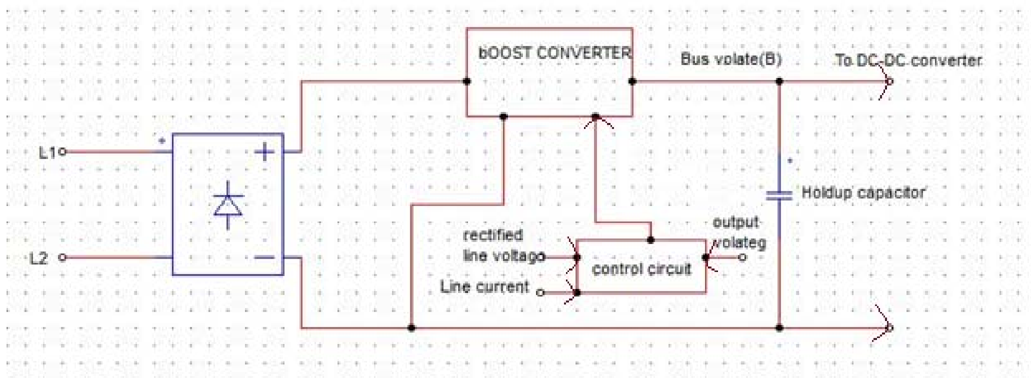


Fig: 2.4 control circuit for adjusting a boost voltage to maintain a sinusoidal input current [3]

2.3.3 High power factor control circuit:

The Schematic diagram of a boost power factor corrector is given below in Fig 2.5. This circuit diagram is similar to boost converter. The diode bridge used here for the purpose of rectifying the input voltage which is AC and it converts the input voltage form AC to DC. And capacitor used for this conversion is kept at the output of the converter Even if any value of capacitor is used in input bridge, its value is very less & it is only used to control if any noise present in the circuit. Constant voltage can obtained at the output side of the converter, but input voltage by some programming forces, the input current to be half wave. Output power obtained at the capacitor output side is in the form of a sine wave. This sine wave has a frequency is equal to two times that of the line frequency & it is never constant [4].

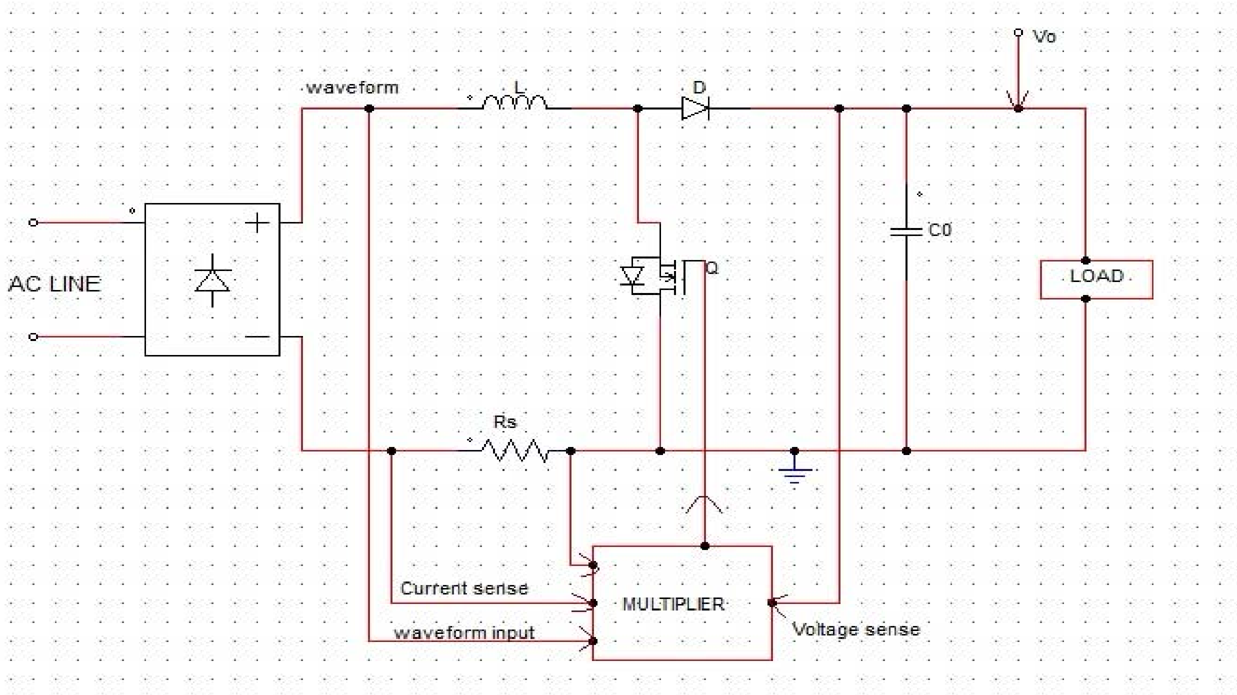


Fig: 2.5 High power factor control circuit [4]

3.1 INTROCUCTION

In most of the cases Boost converters are used as active PF corrector circuits to increase or to improve the power factor of the circuit to reach nearly unity. But now a days to improve the power factor in a better way boost converters are used. These two boost converters are connected in parallel combination to reach that value to unity. Circuit diagrams of both types of PFCs are as given below [9]:

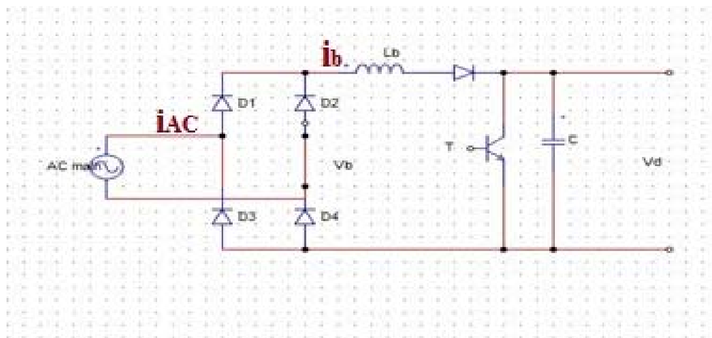


Fig: 3.1 Classical PFC Circuit [9]

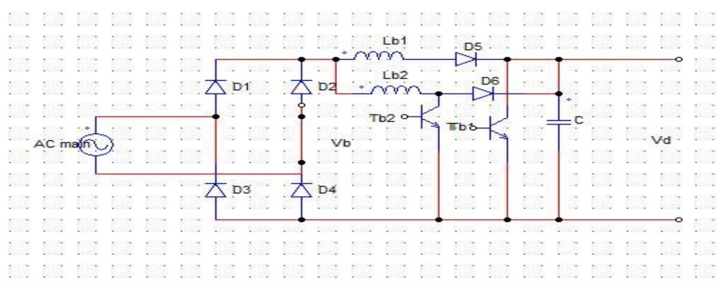


Fig: 3.2 Dual Boost PFC Circuit [9]

Here, we are using a parallel scheme, where L_{b1} and switch T_{b1} are mainly used for the purpose of PFC and L_{b2} and T_{b2} are used for the filtering purpose. Filtering circuit used here does mainly two functions, first one is which improving quality of the input current and it reducing the total switching losses due to the losses while switching the process [9]. The switching losses in the switches are occurs due to the dissimilar values of amplitude of the input current and for dissimilar values of the switching frequency. Parallel combination of this converter is a well-known strategy. It is involved with the phase shift in the two or more number of boost converters are connected in parallel and these are running at same switching frequency [9].

Advantages:

1. Efficiency is high.

2. Initial cost low to develop this type of circuit.
3. Reliability is high.
4. Ripple current is reduced to lower values.
5. Conduction losses will be reduced.

3.2 MODELLING OF DUAL PFC:

From the Fig.4.2, if we consider the dual PFC circuit is running in the CCM, The following can be obtained from the above figures [9]:

$$v_b = L_{b1}\frac{d}{dt}i_{b1} + R_{b1}i_{b1} + f_{b1}v_d \quad \text{(VII)}$$

$$v_b = L_{b2}\frac{d}{dt}i_{b2} + R_{b2}i_{b2} + f_{b2}v_d \quad \text{(VIII)}$$

$$i_{PFC} = i_{b1} + i_{b2} \quad \text{(IX)}$$

Where;

$$v_b(t) = |v_b(t)\sin(\omega t)| \quad \text{(X)}$$

$$f_{b1} = \begin{cases} 0 & if = 1 \ (switch\ on) \\ 1 & if\ T_{b1} = 0 \ (switch\ off) \end{cases}$$

$$f_{b2} = \begin{cases} 0 & if\ T_{b2} = 1 \ (switch\ on) \\ 1 & if\ T_{b2} = 0 \ (switch\ off) \end{cases}$$

The above set of equations can also be written as [9]:

$$f_{b1} = 0 \rightarrow \frac{d}{dt}i_{b1}(t) = \frac{v_b(t)}{L_{b1}} \quad \text{(XI)}$$

$$f_{b1} = 1 \rightarrow \frac{d}{dt}i_{b1}(t) = \frac{v_b(t)-v_d(t)}{L_{b1}} \quad \text{(XII)}$$

$$f_{b2} = 0 \rightarrow \frac{d}{dt}i_{b2}(t) = \frac{v_b(t)}{L_{b2}} \quad \text{(XIII)}$$

$$f_{b2} = 1 \rightarrow \frac{d}{dt}i_{b2}(t) = \frac{v_b(t)-v_d(t)}{L_{b2}} \quad \text{(XIV)}$$

Where;

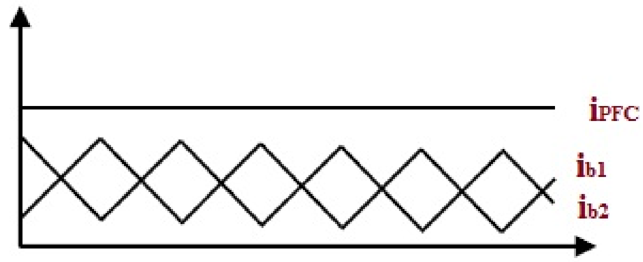
$$i_{b1} \geq 0 \quad i_{b2} \geq 0 \text{ [9]}$$

3.3 DUAL PFC CONTROLLING

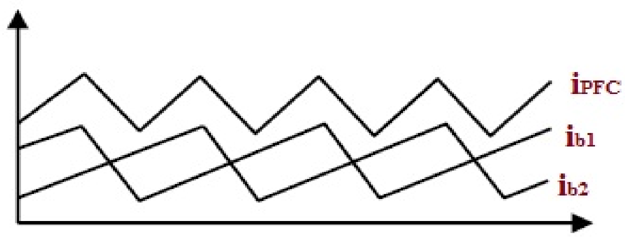
PFC currents i_{b1} and i_{b2} can be attained if v_d(t) >v_b (t).

If the v_d(t) > v_b (t) condition is fulfilled, we can control the derivative of the i_{PFC} [9].

$$\frac{di_{PFC}}{dt} = \frac{d}{dt}i_{b1} + \frac{d}{dt}i_{b2} \quad \text{(XV)}$$



Fig; 3.3 Input current waveform of two interleaved PFC in the ideal running situation [9]



Fig; 3.4 Input current waveform of two interleaved PFC under the actual running situation [9]

CHAPTER IV: CONTROL PRINCIPLES OF DC-DC CONVERTERS

4.1 INTRODUCTION

Control strategy in power system is aimed to develop set of actions those can detect the time evolution of the electrical quantities & enforce them to comply a desired time evolution. Generally an algorithm to control any system can be divided into 3 functional sub-blocks these are defined below [9];

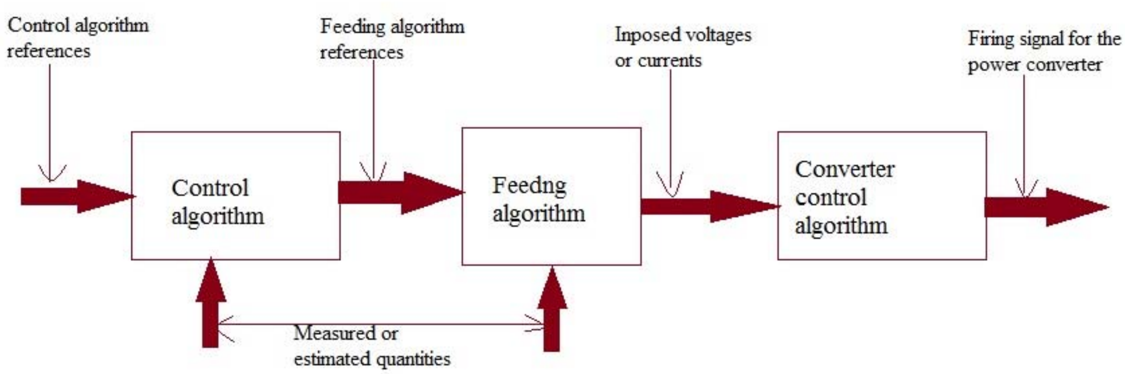


Fig: 4.1 Description and splitting of Control algorithm [9]

1. **Control Algorithm**: which operates to generate reference values to the feeding algorithm according to the reference values imposed to the control algorithm from the outside [9].
2. **Feeding Algorithm**: which gives the imposed voltages or current values for imposing on the converter connected to the input side of the supply system, to comply the time evolution of the referred values which are coming out of the control algorithm side [9].
3. **Algorithm of Converter control**: Which provides the right sequence of firing angles for the power converter based on the information derived from control algorithm & feeding algorithm along with the imposed voltages or currents from the outside [9].

The output DC voltage obtained from the DC-DC converter is regulated under varying load and varying input voltages in the power supply system. The values of the components present in the converter are changing with time, temperature and pressure. Therefore, for controlling the DC output voltage of AC-DC converter, we need to perform the control system with the help of a negative feedback closed loop control system. Most commonly used two closed loop control methods for the pulse width modulation DC-DC converters are shown in the below figures 4.2 and 4.3 [9].

4.2 VOLTAGE MODE CONTROL

Block diagram of this control scheme shown in the below Fig. 4.2, Here, in the voltage control method we need to regulate the output of the converter, sensing output voltage from output side and it is feedback using a resistive voltage divider as shown in the below figure. This output of the converter is then in comparison with a reference voltage V_{ref} which is coming from externally, using error amplifier. The output of the error amplifier is compared with a saw-tooth waveform which is having constant amplitude using the comparator. The output coming from the comparator produces a pulse width modulated signal and it is given to the switches present inside the converter. Pulse width modulated signal is determined and depends on control voltage value. Here frequency of the pulse width modulated signal obtained from comparator is the same as the saw-tooth waveform frequency [3].

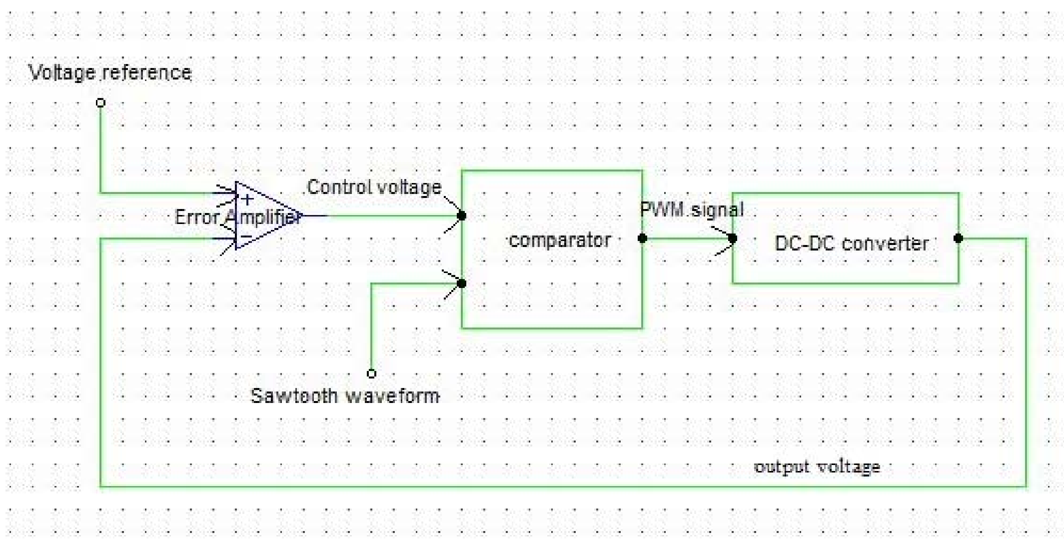


Fig: 4.2 Schematic diagram for voltage mode control [3]

Advantages:

1. Implementation of the hardware is easy and its flexibility.
2. This control strategy provides good load regulation.

Disadvantages:

1. This scheme has a poor line voltage regulation.

4.3 CURRENT MODE CONTROL

Signals obtained in the current form are having several advantages than the voltage signals. If the mechanism of this voltage signals is taken, voltage is the collection of electric flux & it is slow with respect to time. This has been given the idea of designing new area in the development of switch mode power supply. This idea is the current mode control scheme. In current mode control scheme peak or average value of the current is applied in the feed-back loop of the switch mode power converter. This has developed new type of analysis of the circuit but it also introduced complex problems in the system control. These complexities like producing more number of loops in the system [3].

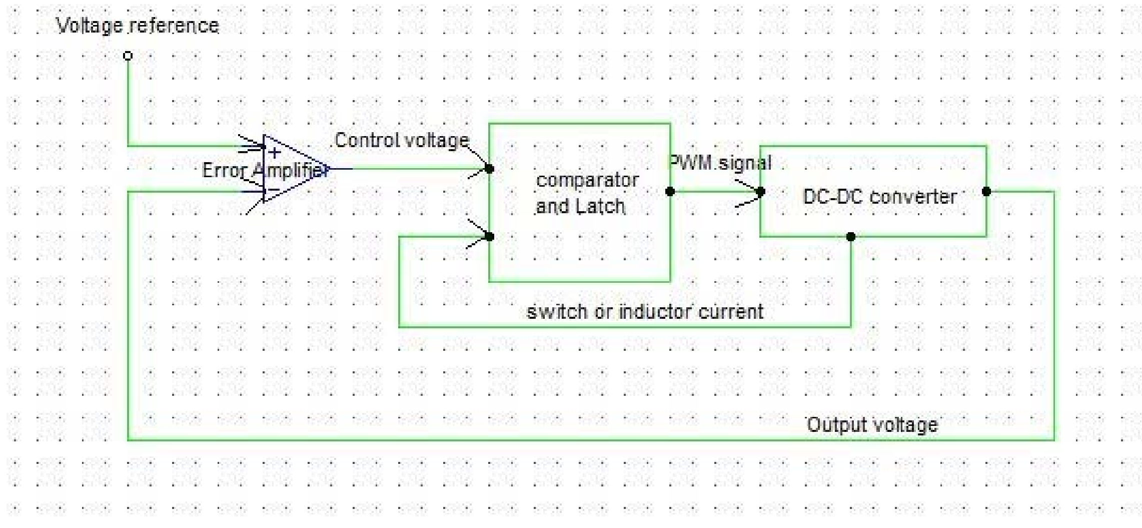


Fig: 4.3 Schematic diagram for current control scheme [3]

Schematic diagram of this control scheme is given in the above Fig. 4.3. This is mainly comprising of an additional inner control loop. In this mode of control the inductor current is converted into to its voltage signal feedback from the output of the converter. This loop is compared with the control voltage, which is coming from the error amplifier, in the comparator. The dynamic response of the converter is altered with the modification of replacing the saw-tooth waveform by this converter current signal. The main difference between these voltage and current mode control is in which manner the control signal is generated [3].

In the voltage mode control scheme, the ramp signal is generated externally from the standpoint of the electrical power plant, and in the current mode control scheme it is generated internally [3].

4.4 OPERATION IN CICM SCHEME:

In this CICM control scheme, in one switching cycle the current in the inductor never reaches a value to zero & there will always some energy will be stored in this inductor.

4.4.1 CONTROL SCHEME FOR CICM OPERATION:

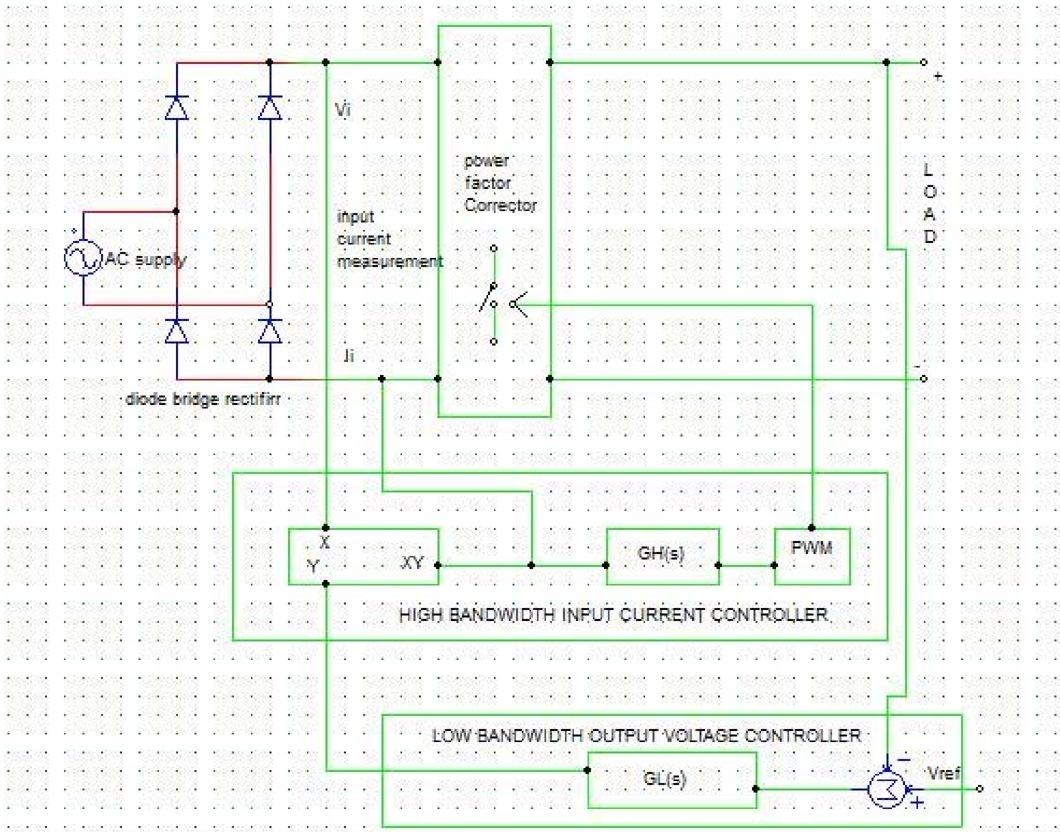


Fig: 4.4 Control scheme for PFC using a switching converter operation in CICM [7]

Control scheme for PFC using a switching converter operation in CICM is shown in the above figure 4.4. The outer loop having the low bandwidth with characteristics $G_L(s)$ is used for keeping the PFC output voltage to be constant during this control scheme and which provide the error signal V_ε the inner loop having the high bandwidth with the characteristics $G_H(s)$ is for controlling input line current. The reference voltage signal V_{XY} is provided by using the multiplier in the system. And this reference voltage is always proportional to the error voltage signal, and this is having a modulating signal with the desired shape of the input line current. The above figure shows the most commonly used situation where the modulating signal is the rectified sinusoidal input voltage V_1 . Depending on which type of analysis used, it will be useful to use modulating signal which is the difference in input voltage and output voltage. This control scheme can be made simple by deleting the multiplier and the line voltage sensor. As this case is considered the modulating signal is $V_{XY} = V_\varepsilon$, & this is a constant over a cycle, because of the control signal which is coming from the outer loop controller output voltage. Hence, this input line current is clinched the value which is proportional to the V_ε and the shape of this line current approaches to a square wave [7].

4.5 IMPLEMENTATION OF INNER LOOP FOR THE CURRENT MODE CONTROL SCHEME:

To implement the inner loop for current mode control there are several techniques are present [3].

1. Peak current control scheme
2. Average current control scheme
3. Hysteresis control scheme
4. Borderline control scheme

4.5.1 HYSTERESIS CONTROL

In this control scheme two currents having sinusoidal in nature, references $I_{V,ref}$, $I_{P,ref}$ generated as the first reference is for the valley and second reference current is for the peak value of inductor current. According to this scheme, if the value of the inductor current goes to a value below lower reference value $I_{V,ref}$ the switch then turned on & if the value of the inductor current goes to a value above the upper reference value $I_{P,ref}$ the switch is turned off, which gives the variable frequency control. But nearer to the zero crossing of line voltage, switch must be kept open in order to avoid the switching frequency too high [3].

Advantages:

- Compensation ramp is not required.
- Distortion in the line current waveform reduces.

Disadvantages:

- Switching frequency is variable.
- We should sense the inductor current.
- It is Control sensitive to the commutation noises [3].

4.5.2 AVERAGE CURRENT CONTROL SCHEME:

Another scheme which allows the better line current waveform is the average current control scheme. In average current control scheme by using a current error amplifier current in the inductor can be sensed and which can be freely filtered, and the pulse width modulated signal can be generated from the output of the error amplifier. In this way the inner loop of current present in the control scheme is reducing the error between the i_g and its reference [3].

Same case can be get from the peak current control scheme. This converter mainly works in the CICM, therefore, with regard to peak current control scheme, the same considerations can be applied. The demerit of peak current control mode can be overcome by the use of the average current mode control scheme by the introduction of a high gain integrating current error amplifier in the current loop. The gain bandwidth characteristics of current loop can be measured by using the compensation network around the current error amplifier. This current loop gain crossover frequency fc can be made approximately the same as in comparison with the peak current mode control scheme, but gain will be greater at lower frequencies [3].

The result is [3]:

1. With a high degree of accuracy, average current can tracks the current program.
2. There is no requirement of Slope compensation, but to achieve stability at the switching frequency, there is a limit to the loop gain.
3. Excellent noise immunity.
4. Control and sensing of the current in any circuit branch is possible.

Advantages:

- In this control scheme switching frequency is constant;
- There is no need of compensating the ramp signal;
- Due to current filtering present, it is not highly sensitive to commutation noise;
- Input current waveform are better than that in case of peak current control.

Disadvantages:

- Sensing of inductor current should be there.
- In this control scheme current error amplifier is required.

4.6 EMI FILTER REQUIREMENTS:

The high frequency ripple of the line current of converters can generates differential mode EMI, while common-mode EMI is a result of secondary, usually parasitic, effects. Typically, the differential-mode EMI is dominant below 2MHz, while the common-mode EMI is considerable above 2MHz [8], [5].

4.6.1 One stage LC filter for attenuating differential-mode EMI:

A high-frequency active PFC stage significantly increases the differential-mode EMI, typically by 30dB to 60dB according to and an EMI filter must be used to comply with EMI standards. There are three main requirements concerning the design of the EMI filter for a PFC stage First requirement: In order to ensure compliancy to the EMI standard, the first requirement for the EMI filter is to provide the required attenuation [8], [5].

4.6.2 Second requirement:

We considering phase diagram of line frequency component of the system current and voltages. We assume here that the input average current i_g is sinusoidal in nature & it is in phase with input voltage V_g of the power factor correction stage, assuming voltage drop is very small across the filter, inductor L_a at line-frequency, essentially equal to the line voltage vi . Proportional to C_a, A angle Φ which is the displacement angle, is introduced among the line current I_i & line voltage V_i due to the capacitive current I_c, which degrades the power factor. This leads to the second requirement for the EMI filter: the displacement angle Φ must be kept low. Hence, the capacitance Ca that can be used is upper limited. C_a <C_{max}, as a consequence, the inductance La is lower limited L_a>L_{min}, In order to have a product L_a C_a that gives the required attenuation [8], [5].

4.6.3 Third requirement:

The third requirement is related to the overall stability of the system. It is known that unstable operation may occur because of the interaction between EMI filter and the power stage. This process is analyzed in several publications, including for peak current mode controlled DC-DC converters, & for PF correctors with average current control scheme. In order to explain it, let us consider thevenin equivalent circuit of EMI filter or the PFC stage interconnection. H_f Is the transfer function of the filter, Z_{of} is the output impedance of EMI filter & Z_{ic} is the input impedance of PFC stage. Here, T_f is a loop gain that should fulfill the Nyquist criterion of the stability system. The interaction is reduced among EMI filter & power converter and thus there is no possibilities for instabilities in the system, if |T_f|<<1. Means that the Z_{of} of EMI filter must be much lower than the Z_{ic} of the power converter, |Z_{of}|<<|Z_{ic}|. The aforementioned condition may be difficult to fulfill in a PFC application. This is because, the modulus of the output impedance Z_{of} has a maximum that is proportional to a L C , at the resonant frequency of the EMI filter, which cannot be set arbitrarily low since Ca is upper limited and La is lower limited. Hence, in a PFC application it is possible to have |T_f|>1, especially at lowZ_{ic}, i.e. at low line voltage and high load current. Thus, if the input impedance Z_{ic} shows an excessive positive phase shift, then T_f of i_c= Z may not satisfy the Nyquist criterion for stability and instabilities occur. For this reason, it is important to know the Z_{ic} of the PFC stage, in order to be able to perform the stability analysis [8], [5].

5.1 IMPLEMENTATION OF HYSTERESIS CONTROL IN BOOST CONVERTER SCHEME:

5.1.1 RECTIFIER CIRCUIT WITHOUT ANY PFC:

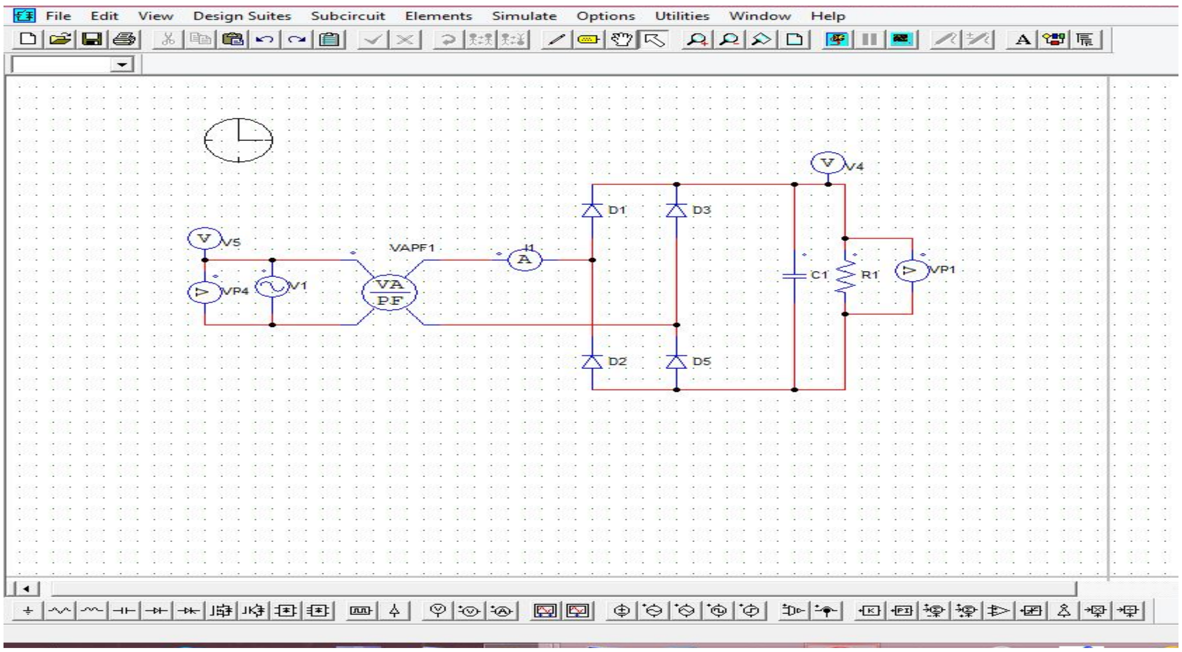


Fig 5.1 : model for AC-DC converter

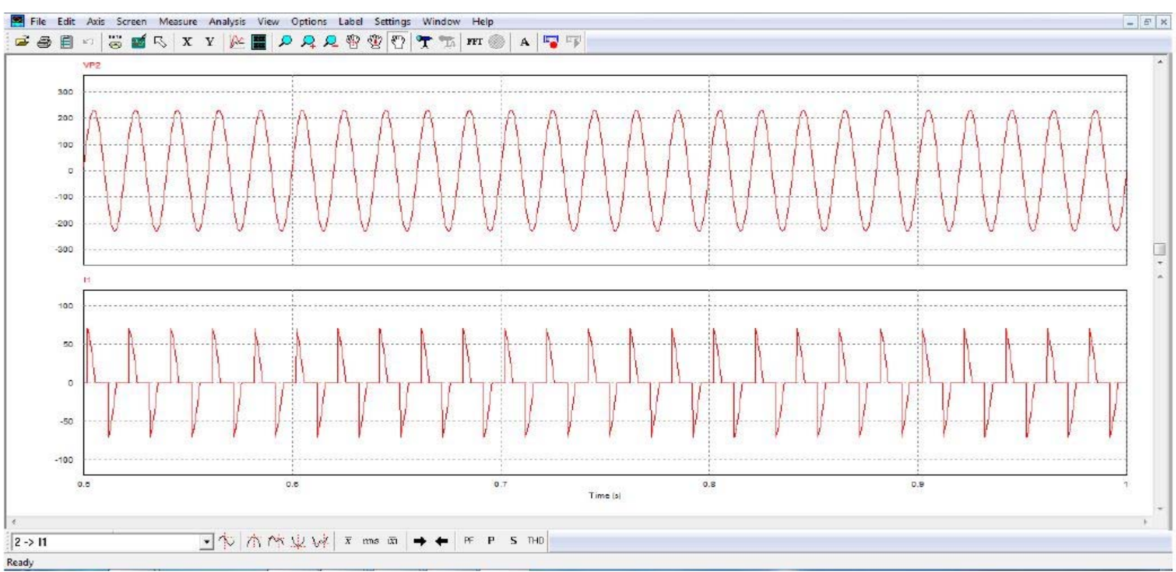


Fig 5.2 : Input voltage and current waveform

5.1.2 IMPLEMENTING HYSTERESIS CONTROL:

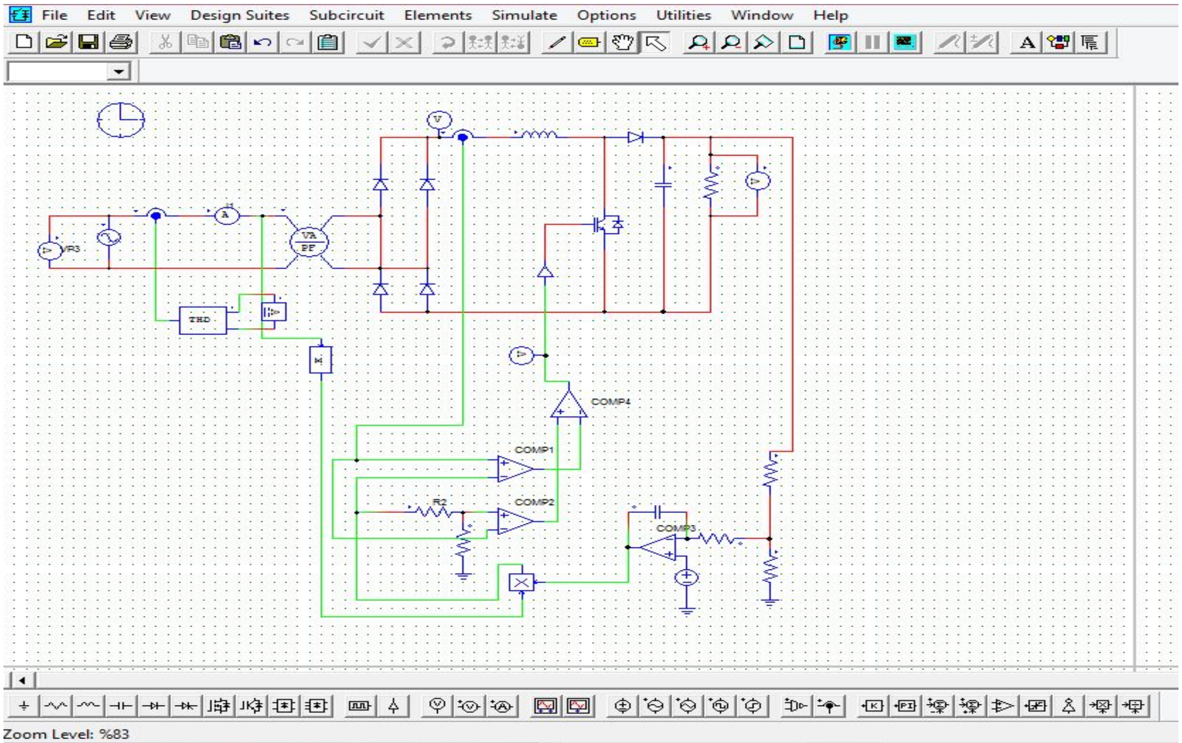


Fig 5.3: Circuit model for hysteresis control scheme

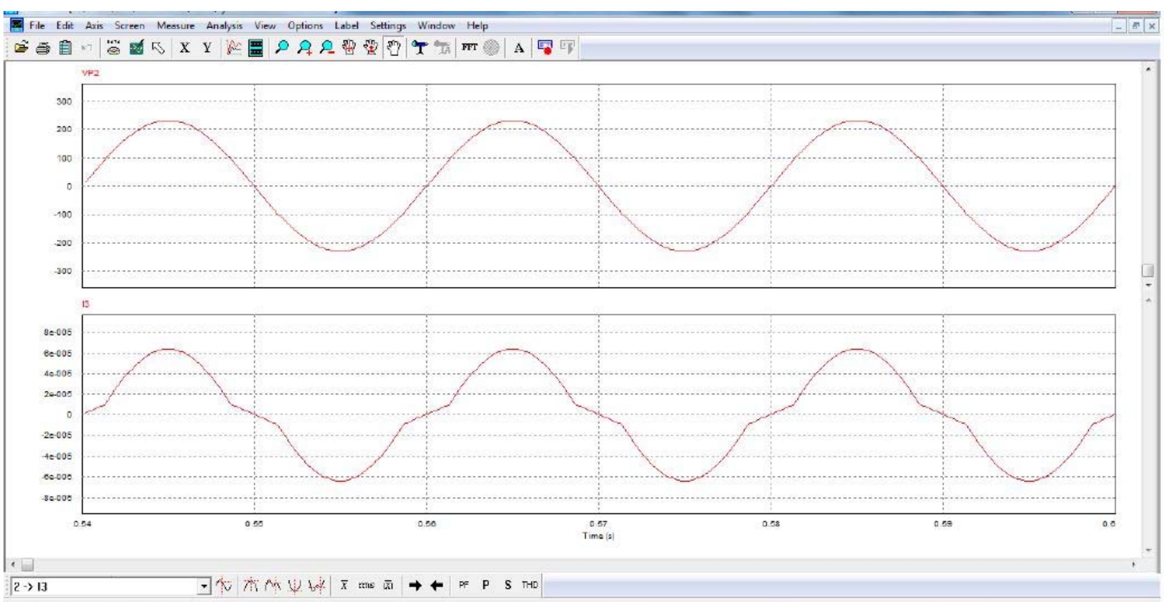


Fig 5.4: input voltage and current waveform for hysteresis control scheme

5.1.3 IMPLEMENTATION OF AVERAGE CURRENT CONTROL IN BOOST CONVERTER:

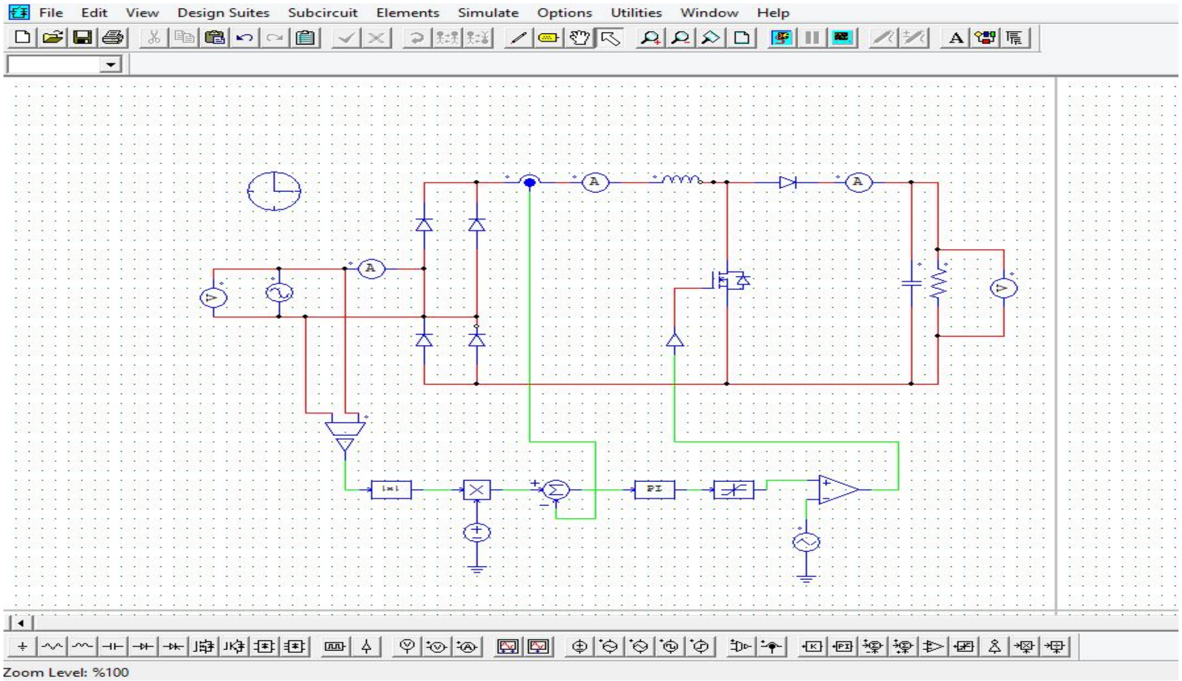


Fig 5.5: Circuit model for average control scheme

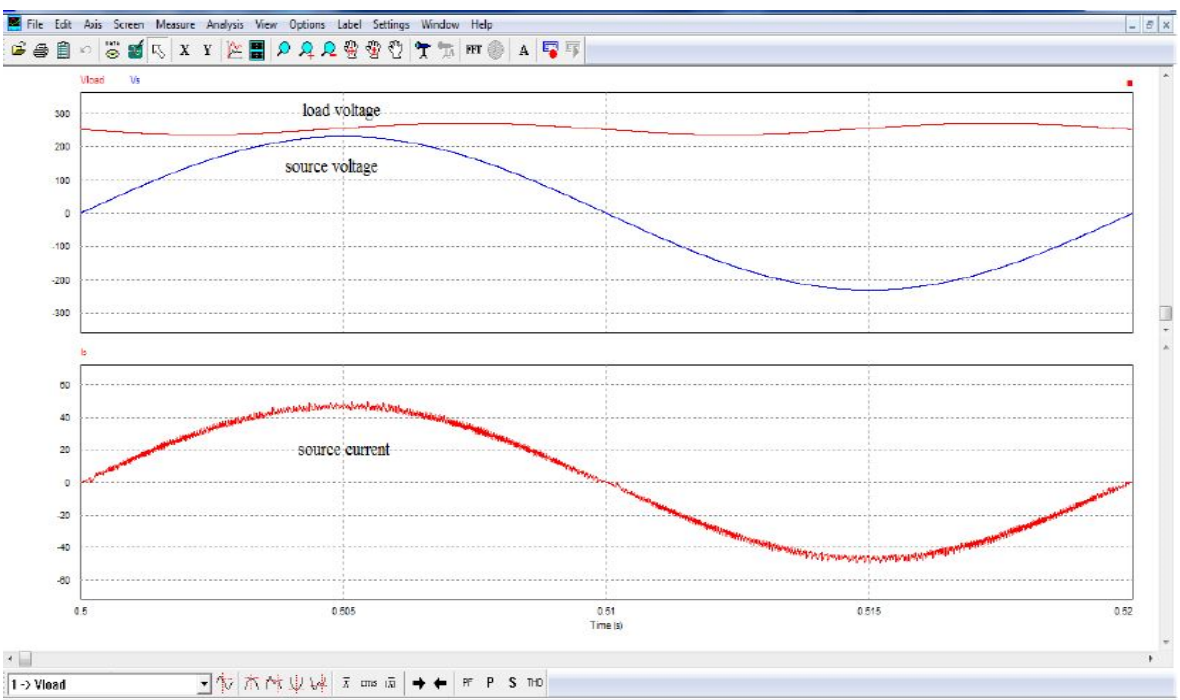


Fig 5.6: voltage and current waveforms in average current control scheme

5.2 IMPLEMENTATION OF DUAL BOOST CONVERTER:

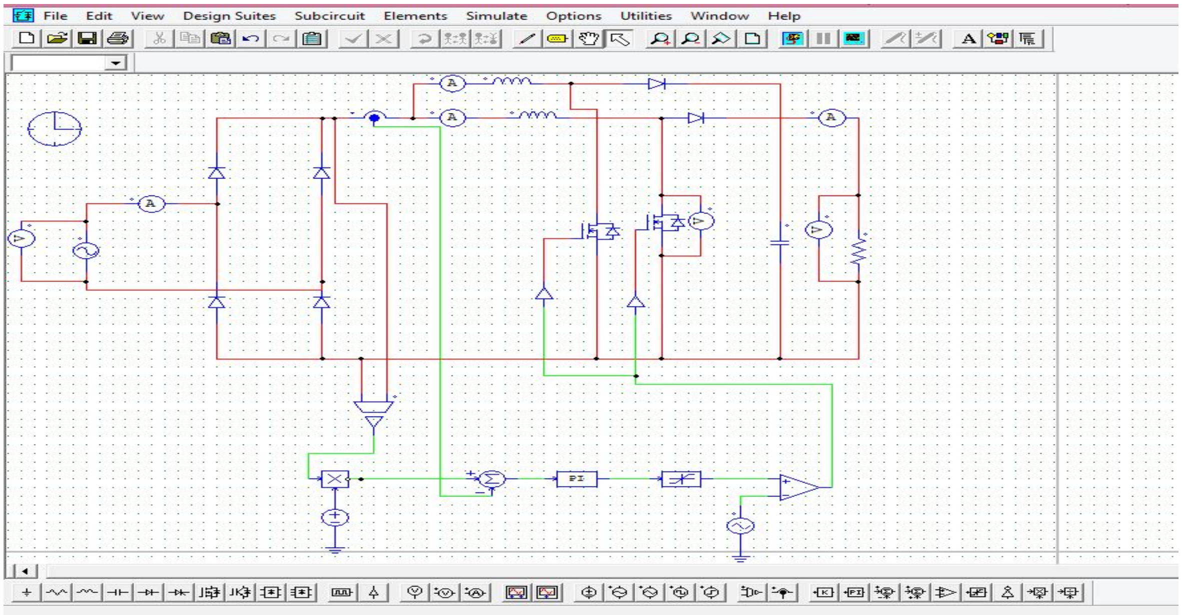


Fig 5.7: Circuit model for dual boost converter

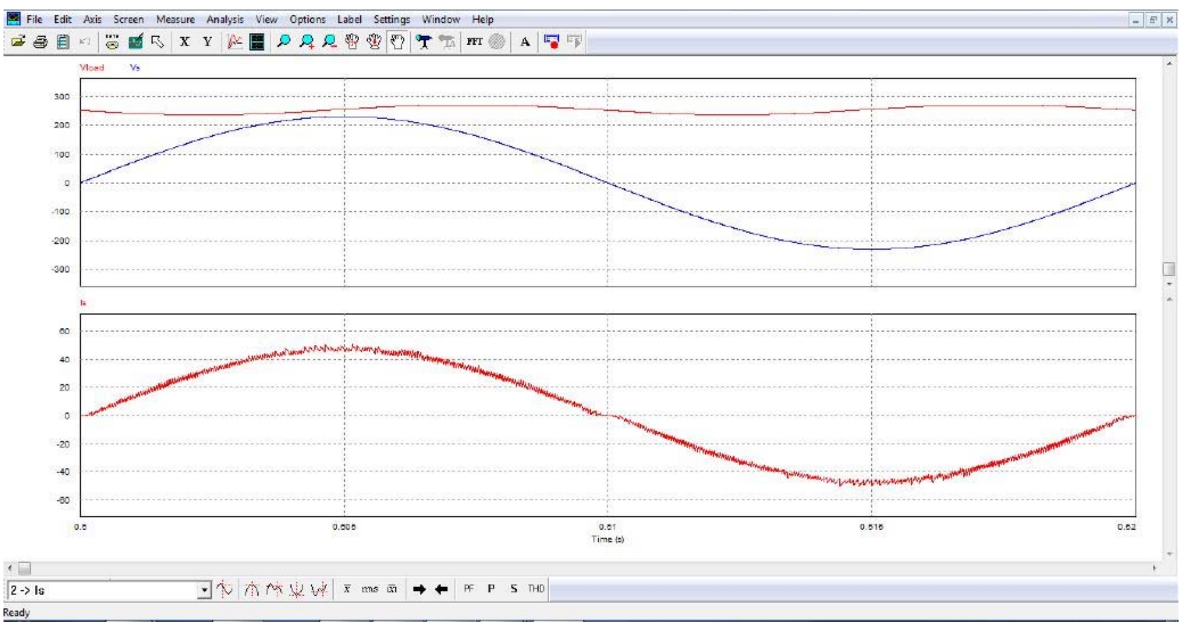


Fig 5.8: voltage and current waveforms for dual boost converter

5.3 IMPLEMENTATION OF EMI FILTER:

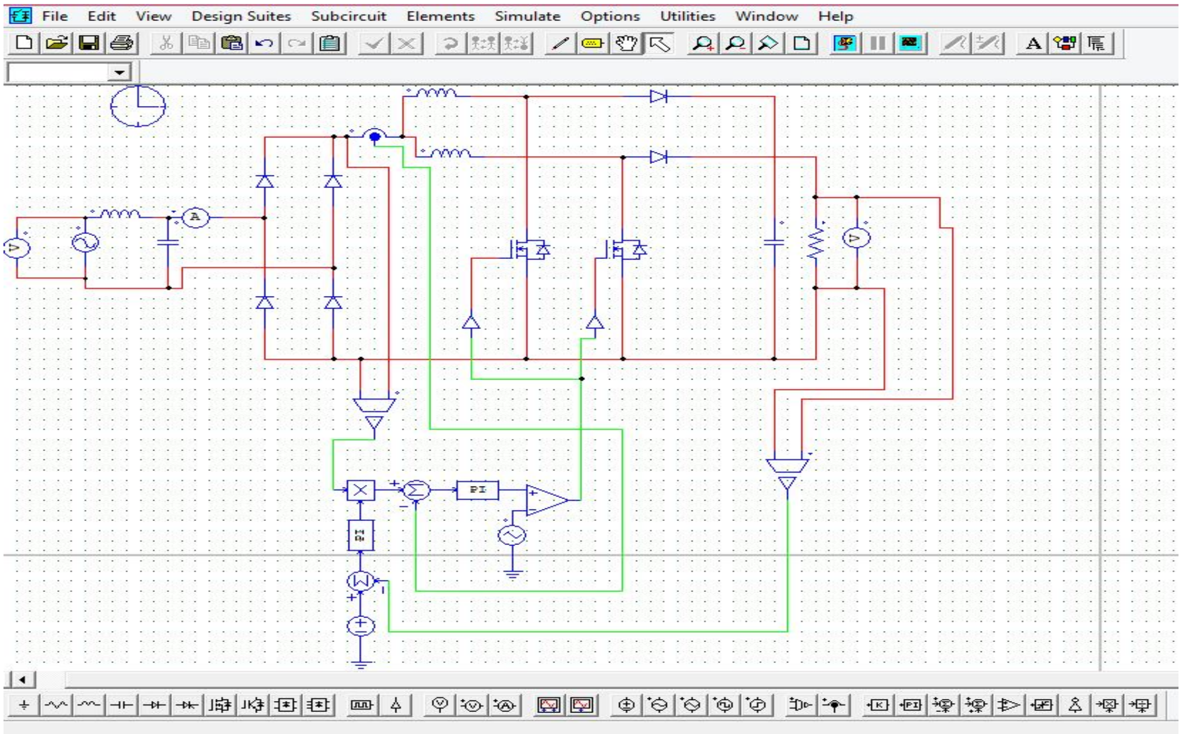


Fig 5.9: Circuit model for dual boost PFC with EMI filter

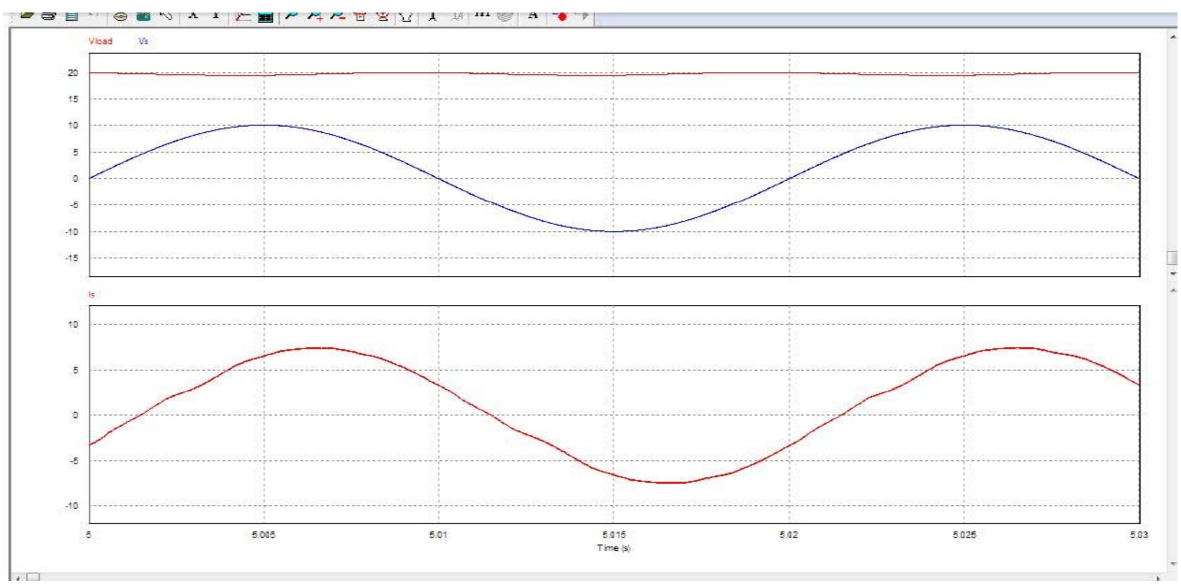


Fig 5.10: voltage and current waveform for dual boost PFC with EMI filter

CHAPTER VI: CONCLUSION

The main aim of this project is to improve the input Power Factor, simultaneously reducing the harmonics present in the input current. Using PSIM software simulation of the circuits were done for elementary rectifier circuits without employing any power factor corrector circuits. These simulations included circuits with and without source side inductors and capacitors. The changes in the input current waveform were observed and studied. Boost converter with hysteresis control technique shows higher input power factor (lower THD).For better input current waveforms and constant switching frequency, we prefer average current control scheme. Further improvement of power factor has been done by using parallel boost converter techniques. EMI filter has been added in order to further decrease the total harmonic distortion. Further improvement can be done by using soft-switching techniques.

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